A dynamic-thermodynamic sea ice model on an Arakawa C grid for coupled ocean and sea ice state estimation

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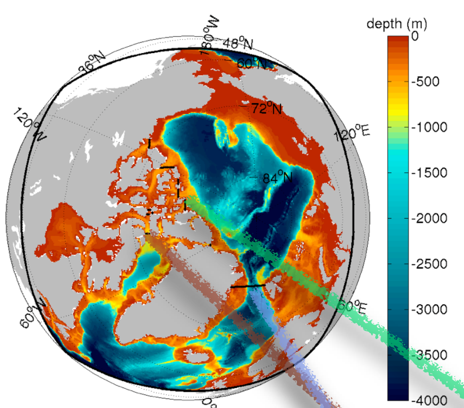
Overview

As part of an ongoing effort to obtain a best possible, time-evolving analysis of most available ocean and sea ice data, a dynamic and thermodynamic sea-ice model has been coupled to the Massachusetts Institute of Technology general circulation model (MITgcm). The sea ice model components were borrowed from current-generation climate models but they were reformulated with a finite-volume discretization on an Arakawa C grid in order to match the MITgcm oceanic grid and they were modified in many ways to permit efficient and accurate automatic differentiation. Features include:

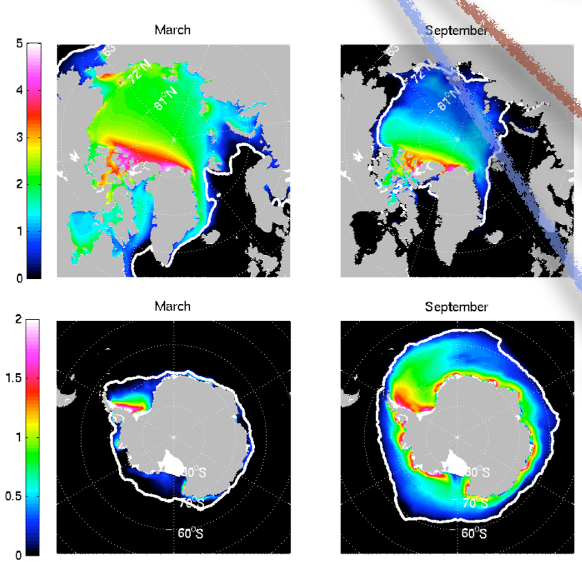
- viscous-plastic rheology with line-successive-over-relaxation (LSOR) or elastic-viscous-plastic (EVP) solver
- either zero-heat-capacity for two-layer thermodynamics following Winton (2000)
- ice-ocean stress can be formulated as in Hibler and Bryan (1987)
- ice concentration and thickness, snow, and ice salinity or enthalpy can be advected by sophisticated, conservative advection schemes with flux limiters
- growth and melt parameterizations have been refined and extended in order to allow for automatic differentiation of the code

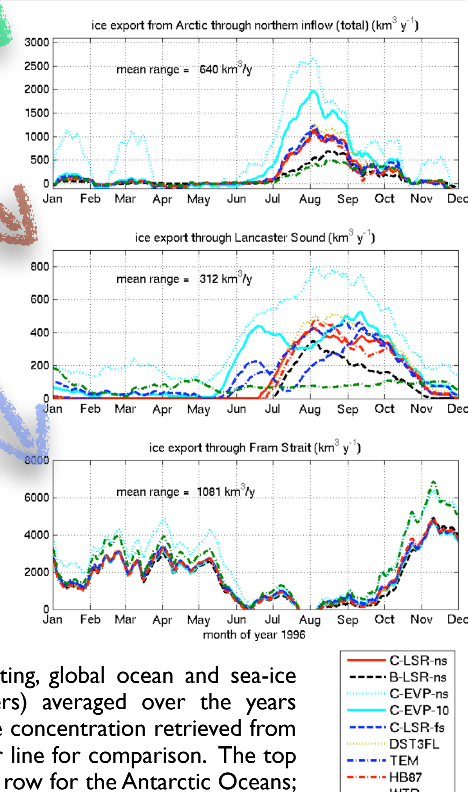


List of experiments and acronyms

C-LSR-ns	baseline C-grid LSOR solver, no-slip bcs
B-LSR-ns	original B-grid LSOR
C-EVP-ns	C-grid EVP solver no-slip, Δt=150s
C-EVP-10	C-grid EVP solver no-slip, Δt=10s
C-LSR-fs	C-grid LSOR solver, free slip
DST3FL	C-grid LSOR solver, 3rd adv., flux lim.
TEM	C-grid LSOR, truncated ellipse method
HB87	C-grid LSOR, Hibler and Bryan (1987) stress
WTD	C-grid LSOR, Winton (2000) thermodynamics

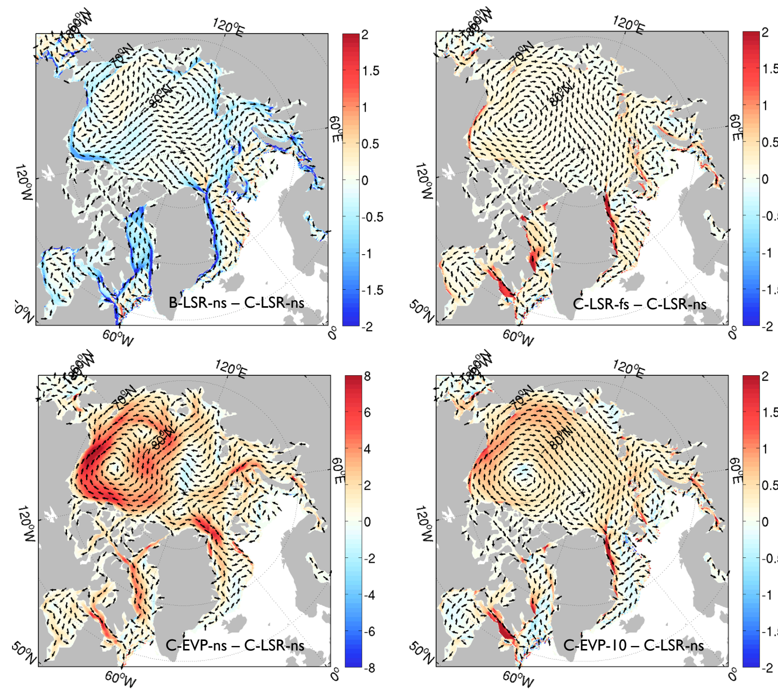
Above: Arctic model domain carved out from global model (below) with various sections.





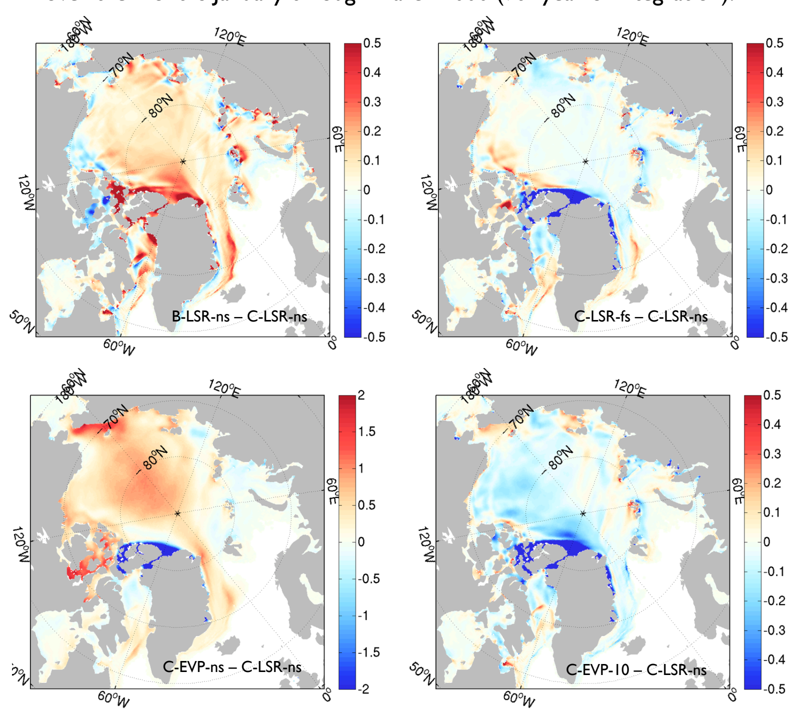
Example Arctic and Antarctic results from an eddy-permitting, global ocean and sea-ice simulation: Sea ice thickness distribution (color, in meters) averaged over the years 1992--2002. The ice edge estimated as the 15% isoline of ice concentration retrieved from passive microwave satellite data is drawn as a white contour line for comparison. The top row shows the results for the Arctic Ocean and the bottom row for the Antarctic Oceans; the left column shows distributions for March and the right column for September.

Sensitivity to configuration details

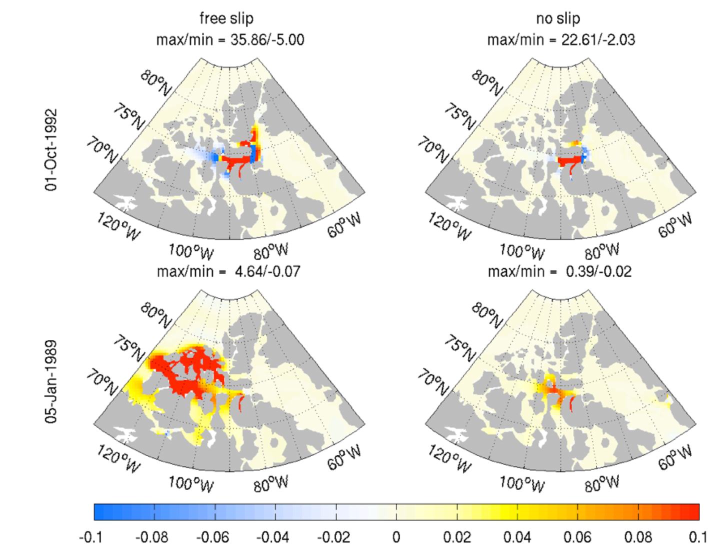


Above: Ice drift velocity differences (cm/s) to the C-LSR-ns solution averaged over the first 3~months of integration; color indicates speed differences and vectors indicate direction only. The direction vectors are smoothed and plotted for every eighth velocity point. The largest difference are found between LSOR and EVP solver. Note the varying color scale.

Below: Ice thickness differences (m) to the C-LSR-ns solution, averaged over the months January through March 2000 (9th year of integration).

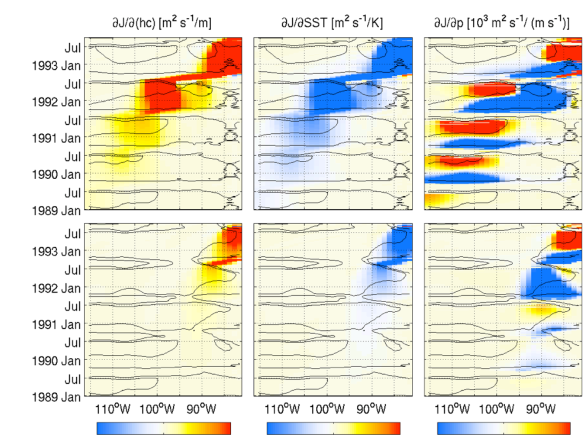


Example results of adjoint model: Multi-year sensitivities of ice export through the Canadian Arctic Archipelago



Above: Snapshots of snow & ice export sensitivities through Lancaster Sound with respect to ice thickness for free-slip (left) and no-slip (right) solution (m/s).

Below: Longitude vs. time diagrams of snow & ice export sensitivities through the Lancaster sound to ice thickness (left), sea surface temperature (middle), and precipitation (right).



Conclusions

- Sea ice models are sensitive to changes in discretization (B-grid vs. C-grid) and very sensitive to solver technology (LSOR vs. EVP).
- The EVP solution converges towards the LSOR solution for very many sub-cycling time steps.
- The adjoint model provides complementary insight into causal links within the ocean/sea-ice/atmospheric-forcing coupled system. This technique will be used for coupled ocean/sea-ice state estimation.

References

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